



Section 2

Rational Formula



Rational Formula

$$Q = C I A$$

- ↳ Q = Runoff in cubic feet per second (cfs)
- ↳ C = Runoff coefficient (dimensionless)
- ↳ I = Rainfall intensity (inches per hour)
- ↳ A = Drainage area (acres)
- ↳ $1 \text{ cfs} = 1.008 \text{ acre-in/hr}$
 $\text{in/hr} * \text{hr} / 3600 \text{s} * \text{ft} / 12 \text{in} * \text{acre} @ 43560 \text{sf/acre}$

Runoff Coefficient (C)

| Type of Cover | Flat | Rolling 2%-10% | Hilly Over 10% |
|----------------------------------|------|----------------|----------------|
| Pavement and Roofs | 0.90 | 0.90 | 0.90 |
| Earth Shoulders | 0.50 | 0.50 | 0.50 |
| Drives and Walks | 0.75 | 0.80 | 0.85 |
| Gravel Pavement | 0.50 | 0.55 | 0.60 |
| City Business Areas | 0.80 | 0.85 | 0.85 |
| Suburban Residential | 0.25 | 0.35 | 0.40 |
| Single Family Residential | 0.30 | 0.40 | 0.50 |
| Multi Units, Detached | 0.40 | 0.50 | 0.60 |
| Multi Units, Attached | 0.60 | 0.65 | 0.70 |
| Lawns, Very Sandy Soil | 0.05 | 0.07 | 0.10 |
| Lawns, Sandy Soil | 0.10 | 0.15 | 0.20 |
| Lawns, Heavy Soil | 0.17 | 0.22 | 0.35 |
| Grass Shoulders | 0.25 | 0.25 | 0.25 |
| Side Slopes, Earth | 0.60 | 0.60 | 0.60 |
| Side Slopes, Turf | 0.30 | 0.30 | 0.30 |
| Median Areas, Turf | 0.25 | 0.30 | 0.30 |
| Cultivated Land, Clay and Loam | 0.50 | 0.55 | 0.60 |
| Cultivated Land, Sand and Gravel | 0.25 | 0.30 | 0.35 |
| Industrial Areas, Light | 0.50 | 0.70 | 0.80 |
| Industrial Areas, Heavy | 0.60 | 0.80 | 0.90 |
| Parks and Cemeteries | 0.10 | 0.15 | 0.25 |
| Playgrounds | 0.20 | 0.25 | 0.30 |
| Woodland and Forests | 0.10 | 0.15 | 0.20 |
| Meadows and Pasture Land | 0.25 | 0.30 | 0.35 |
| Pasture with Frozen Ground | 0.40 | 0.45 | 0.50 |
| Unimproved Areas | 0.10 | 0.20 | 0.30 |

Figure 2-4.2
Runoff Coefficients for the Rational Method — 10-Year Return Frequency

25-yr increase C by 10%, 100-yr increase C by 25%
not to exceed 1.0

Rainfall Intensity (I)

In order to determine the rainfall intensity, first the travel time (T_t) for each of the basin segments must be calculated.

Travel Time

$$T_t = \frac{\Delta L}{K S^{0.5}} \quad \text{or} \quad = \frac{(\Delta L)^{1.5}}{K (\Delta H)^{0.5}}$$

where:

T_t = Travel time for each basin segment (min)

ΔL = Length of drainage basin in feet (m)

K = Ground cover coefficient in ft/min (m/min)

S = Average slope ($\Delta H/\Delta L$) in ft/ft (m/m)

ΔH = Height of drainage basin in ft (m)

Next, the time of concentration (T_c) for the entire basin must be determined. The time of concentration is the time required for the surface runoff from the most remote part of the basin to reach the point of interest. It is equal to the sum of the individual travel times for each basin segment.

Time of Concentration

$$T_c = T_{t1} + T_{t2} + \dots + T_{tn}$$

The peak flow that occurs at the point of interest is produced by that rainfall intensity which is maintained for a time equal to the time of concentration. This occurs because at that particular time (equal to the T_c), the entire basin will be contributing runoff to the point of interest.

Rainfall Intensity (I)

| Type of Cover | | K (metric) | K (English) |
|--------------------------------|--------------|---------------|----------------|
| Forest with heavy ground cover | | 50 | 150 |
| Minimum tillage cultivation | | 75 | 280 |
| Short pasture grass or lawn | | 125 | 420 |
| Nearly bare ground | | 200 | 600 |
| Small roadside ditch w/grass | | 275 | 900 |
| Paved area | | 375 | 1,200 |
| Gutter flow | 100 mm deep | 450 | 1,500 |
| | 150 mm deep | 725 | 2,400 |
| | 200 mm deep | 950 | 3,100 |
| Storm Sewers | 300 mm diam. | 925 | 3,000 |
| | 450 mm diam. | 1,200 | 3,900 |
| | 600 mm diam. | 1,425 | 4,700 |
| Open Channel Flow (n = .040) | 300 mm deep | 350 | 1,100 |
| Narrow Channel (w/d =1) | 600 mm deep | 550 | 1,800 |
| | 1.20 m deep | 850 | 2,800 |
| Open Channel Flow (n = .040) | 300 mm deep | 600 | 2,000 |
| Wide Channel (w/d =9) | 600 mm deep | 950 | 3,100 |
| | 1.20 m deep | 1,525 | 5,000 |

Figure 2-4.3
Ground Cover Coefficients

The equation for calculating rainfall intensity is:

$$I = \frac{m}{(T_c)^n}$$

where: I = Rainfall intensity in millimeters per hour (inches per hour in English units)

T_c = Time of concentration in minutes

m and n = Coefficients in dimensionless units (see Figures 2-4.4A and 2-4.4B)

Index to Rainfall Coefficients (English Units)

Figure 2-4.4B

| Location | 2-Year MRI | | 5-Year MRI | | 10-Year MRI | | 25-Year MRI | | 50-Year MRI | | 100-Year MRI | |
|------------------------|------------|-------|------------|-------|-------------|-------|-------------|-------|-------------|-------|--------------|-------|
| | m | n | m | n | m | n | m | n | m | n | m | n |
| Aberdeen and Hoquiam | 5.10 | 0.488 | 6.22 | 0.488 | 7.06 | 0.487 | 8.17 | 0.487 | 9.02 | 0.487 | 9.86 | 0.487 |
| Bellingham | 4.29 | 0.549 | 5.59 | 0.555 | 6.59 | 0.559 | 7.90 | 0.562 | 8.89 | 0.563 | 9.88 | 0.565 |
| Bremerton | 3.79 | 0.480 | 4.84 | 0.487 | 5.63 | 0.490 | 6.68 | 0.494 | 7.47 | 0.496 | 8.26 | 0.498 |
| Centralia and Chehalis | 3.63 | 0.506 | 4.85 | 0.518 | 5.76 | 0.524 | 7.00 | 0.530 | 7.92 | 0.533 | 8.86 | 0.537 |
| Clarkston and Colfax | 5.02 | 0.628 | 6.84 | 0.633 | 8.24 | 0.635 | 10.07 | 0.638 | 11.45 | 0.639 | 12.81 | 0.639 |
| Colville | 3.48 | 0.558 | 5.44 | 0.593 | 6.98 | 0.610 | 9.07 | 0.626 | 10.65 | 0.635 | 12.26 | 0.642 |
| Ellensburg | 2.89 | 0.590 | 5.18 | 0.631 | 7.00 | 0.649 | 9.43 | 0.664 | 11.30 | 0.672 | 13.18 | 0.678 |
| Everett | 3.69 | 0.556 | 5.20 | 0.570 | 6.31 | 0.575 | 7.83 | 0.582 | 8.96 | 0.585 | 10.07 | 0.586 |
| Forks | 4.19 | 0.410 | 5.12 | 0.412 | 5.84 | 0.413 | 6.76 | 0.414 | 7.47 | 0.415 | 8.18 | 0.416 |
| Hoffstadt Cr. (SR 504) | 3.96 | 0.448 | 5.21 | 0.462 | 6.16 | 0.469 | 7.44 | 0.476 | 8.41 | 0.480 | 9.38 | 0.484 |
| Hoodsport | 4.47 | 0.428 | 5.44 | 0.428 | 6.17 | 0.427 | 7.15 | 0.428 | 7.88 | 0.428 | 8.62 | 0.428 |
| Kelso and Longview | 4.25 | 0.507 | 5.50 | 0.515 | 6.45 | 0.519 | 7.74 | 0.524 | 8.70 | 0.526 | 9.67 | 0.529 |
| Leavenworth | 3.04 | 0.530 | 4.12 | 0.542 | 5.62 | 0.575 | 7.94 | 0.594 | 9.75 | 0.606 | 11.08 | 0.611 |
| Moses Lake | 2.61 | 0.583 | 5.05 | 0.634 | 6.99 | 0.655 | 9.58 | 0.671 | 11.61 | 0.681 | 13.63 | 0.688 |
| Mt. Vernon | 3.92 | 0.542 | 5.25 | 0.552 | 6.26 | 0.557 | 7.59 | 0.561 | 8.60 | 0.564 | 9.63 | 0.567 |
| Naselle | 4.57 | 0.432 | 5.67 | 0.441 | 6.14 | 0.432 | 7.47 | 0.443 | 8.05 | 0.440 | 8.91 | 0.436 |
| Olympia | 3.82 | 0.466 | 4.86 | 0.472 | 5.62 | 0.474 | 6.63 | 0.477 | 7.40 | 0.478 | 8.17 | 0.480 |
| Omak | 3.04 | 0.583 | 5.06 | 0.618 | 6.63 | 0.633 | 8.74 | 0.647 | 10.35 | 0.654 | 11.97 | 0.660 |
| Pasco and Kennewick | 2.89 | 0.590 | 5.18 | 0.631 | 7.00 | 0.649 | 9.43 | 0.664 | 11.30 | 0.672 | 13.18 | 0.678 |
| Port Angeles | 4.31 | 0.530 | 5.42 | 0.531 | 6.25 | 0.531 | 7.37 | 0.532 | 8.19 | 0.532 | 9.03 | 0.532 |
| Poulsbo | 3.83 | 0.506 | 4.98 | 0.513 | 5.85 | 0.516 | 7.00 | 0.519 | 7.86 | 0.521 | 8.74 | 0.523 |
| Quets | 4.26 | 0.422 | 5.18 | 0.423 | 5.87 | 0.423 | 6.79 | 0.423 | 7.48 | 0.423 | 8.18 | 0.424 |
| Seattle | 3.56 | 0.515 | 4.83 | 0.531 | 5.62 | 0.530 | 6.89 | 0.539 | 7.88 | 0.545 | 8.75 | 0.545 |
| Sequim | 3.50 | 0.551 | 5.01 | 0.569 | 6.16 | 0.577 | 7.69 | 0.585 | 8.88 | 0.590 | 10.04 | 0.593 |
| Snoqualmie Pass | 3.61 | 0.417 | 4.81 | 0.435 | 6.56 | 0.459 | 7.72 | 0.459 | 8.78 | 0.461 | 10.21 | 0.476 |
| Spokane | 3.47 | 0.556 | 5.43 | 0.591 | 6.98 | 0.609 | 9.09 | 0.626 | 10.68 | 0.635 | 12.33 | 0.643 |
| Stevens Pass | 4.73 | 0.462 | 6.09 | 0.470 | 8.19 | 0.500 | 8.53 | 0.484 | 10.61 | 0.499 | 12.45 | 0.513 |
| Tacoma | 3.57 | 0.516 | 4.78 | 0.527 | 5.70 | 0.533 | 6.93 | 0.539 | 7.86 | 0.542 | 8.79 | 0.545 |
| Vancouver | 2.92 | 0.477 | 4.05 | 0.496 | 4.92 | 0.506 | 6.06 | 0.515 | 6.95 | 0.520 | 7.82 | 0.525 |
| Walla Walla | 3.33 | 0.569 | 5.54 | 0.609 | 7.30 | 0.627 | 9.67 | 0.645 | 11.45 | 0.653 | 13.28 | 0.660 |
| Wenatchee | 3.15 | 0.535 | 4.88 | 0.566 | 6.19 | 0.579 | 7.94 | 0.592 | 9.32 | 0.600 | 10.68 | 0.605 |
| Yakima | 3.86 | 0.608 | 5.86 | 0.633 | 7.37 | 0.644 | 9.40 | 0.654 | 10.93 | 0.659 | 12.47 | 0.663 |

Drainage Area (A)

- ☞ Greatest accuracy for basins that are 100 acres (40 hectares) or less
- ☞ Can be used for basins up to 1000 acres (400 hectares)
- ☞ Basin size should not exceed the lower limit specified for USGS Regression Equations



Hydrology By The Rational Formula

| | |
|---------------|---------|
| SR | Project |
| Calculated By | Date |

| EQUATIONS |
|--|
| $T_c = \frac{L}{K\sqrt{S}} = \frac{L^{1.5}}{K\sqrt{\Delta H}}$ |
| $I = \frac{m}{(T_c)^n}$ |
| $Q = \frac{CIA}{K_c}$ |

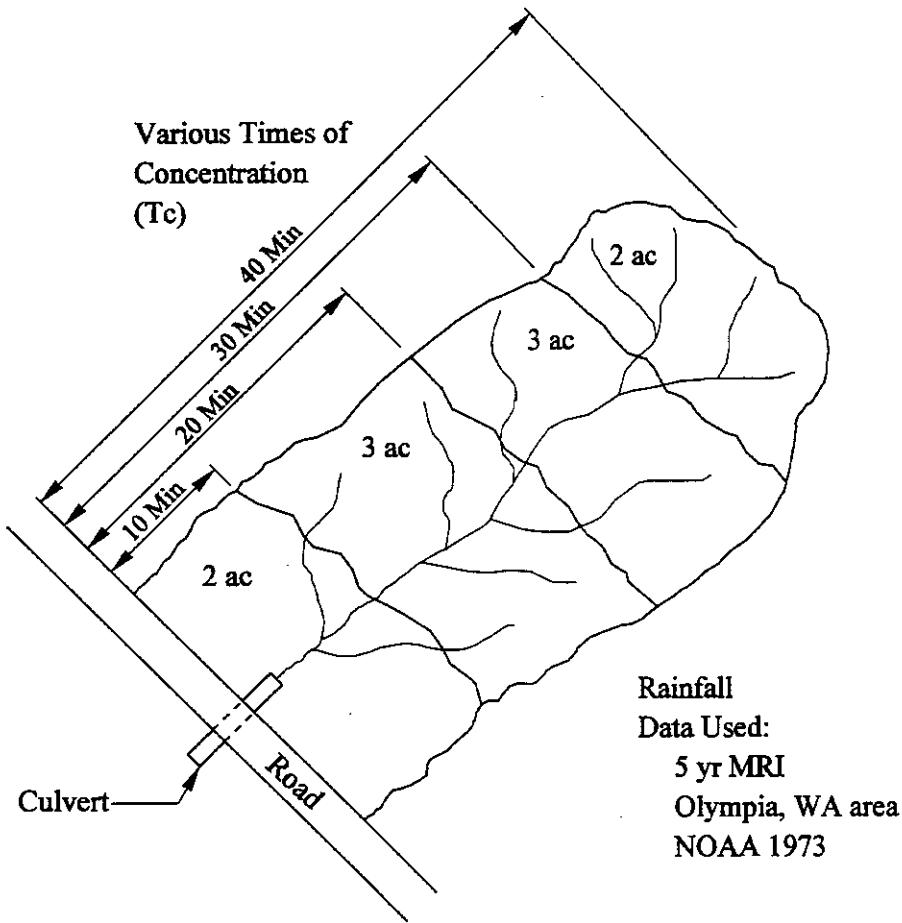
| LEGEND | |
|---|-----------------------------------|
| Q = Flow | T_c = Time of concentration |
| L = Length of drainage basin | m & n = Rainfall coefficients |
| S = Average slope | K_c = Conversion factor |
| K = Ground cover coefficient | C = Runoff coefficient |
| ΔH = Change in elevation of basin | A = Drainage area |

| Description Of Area | MRI | L | ΔH | S | K | T_c | Rainfall Coeff | | K_c | C | I | A | Q |
|---------------------|-----|---|------------|---|---|-------|----------------|---|-------|---|---|---|---|
| | | | | | | | m | n | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | |

Figure 2-4.1
Hydrology by the Rational Method

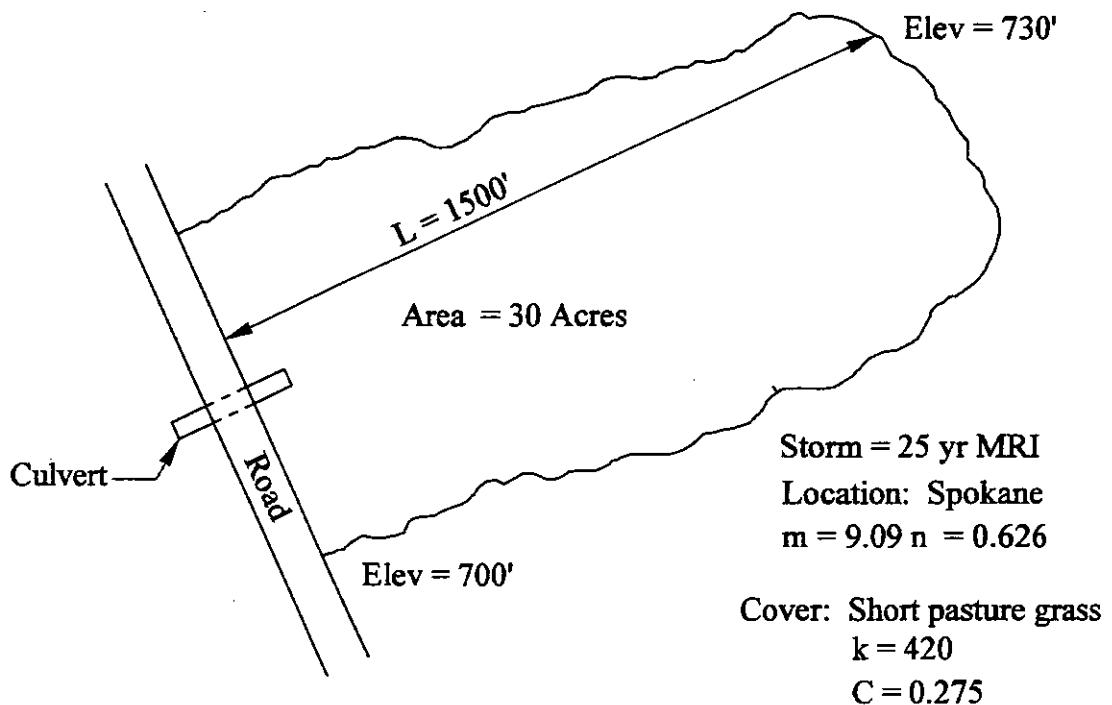
Rational Formula

Typical 10 Acre Drainage Basin



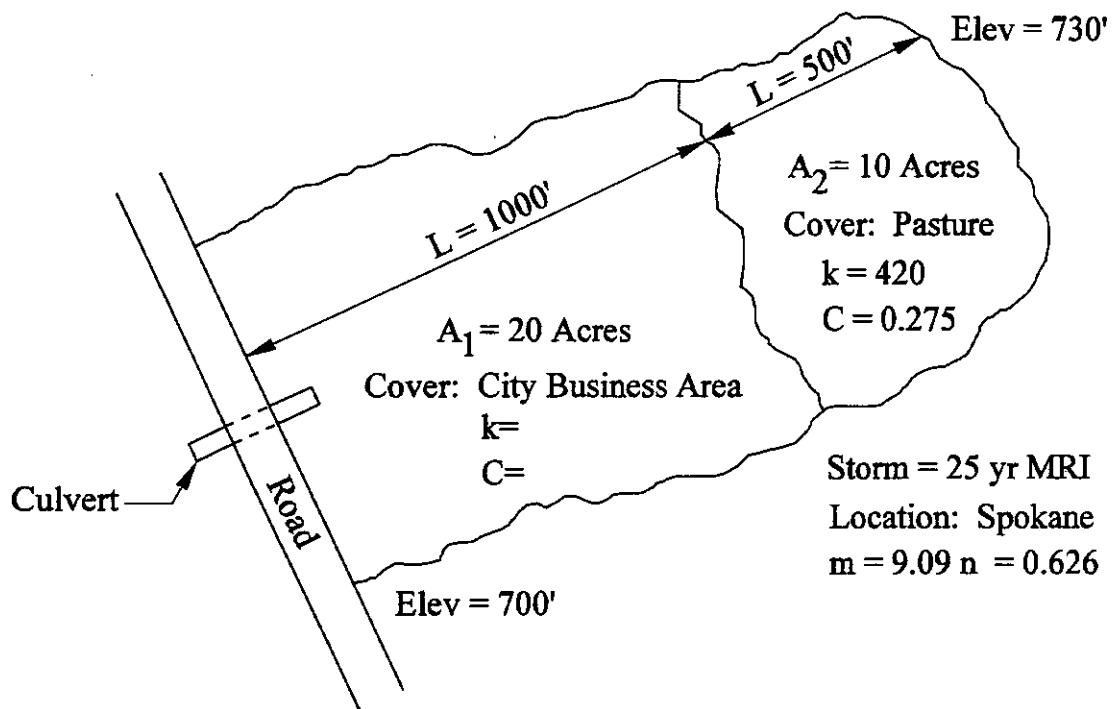
| Rainfall Duration (Min) | Rainfall Intensity (in/hr) | C*A (Acres) | Q = CIA (cfs) |
|-------------------------|----------------------------|-------------|---------------|
| 10 | 1.72 | 2 | 3.44 |
| 20 | 1.30 | 5 | 6.50 |
| 30 | 1.01 | 8 | 8.08 |
| 40 | 0.89 | 10 | 8.90 |
| 60 | 0.64 | 10 | 6.36 |
| 100 | 0.53 | 10 | 5.30 |
| 1440 | 0.16 | 10 | 1.61 |

Rational Formula Example



Determine the runoff Q that will occur in this basin.

Rational Formula Problem



Determine the runoff that will occur due to development in the basin. Assume that the city business area has paved and gutter flow.

$$\text{Remember: } T_{C_{\text{basin}}} = T_{C_{A_1}} + T_{C_{A_2}}$$

$$Q = (\sum CA)I = [C_1 A_1 + C_2 A_2] * I$$